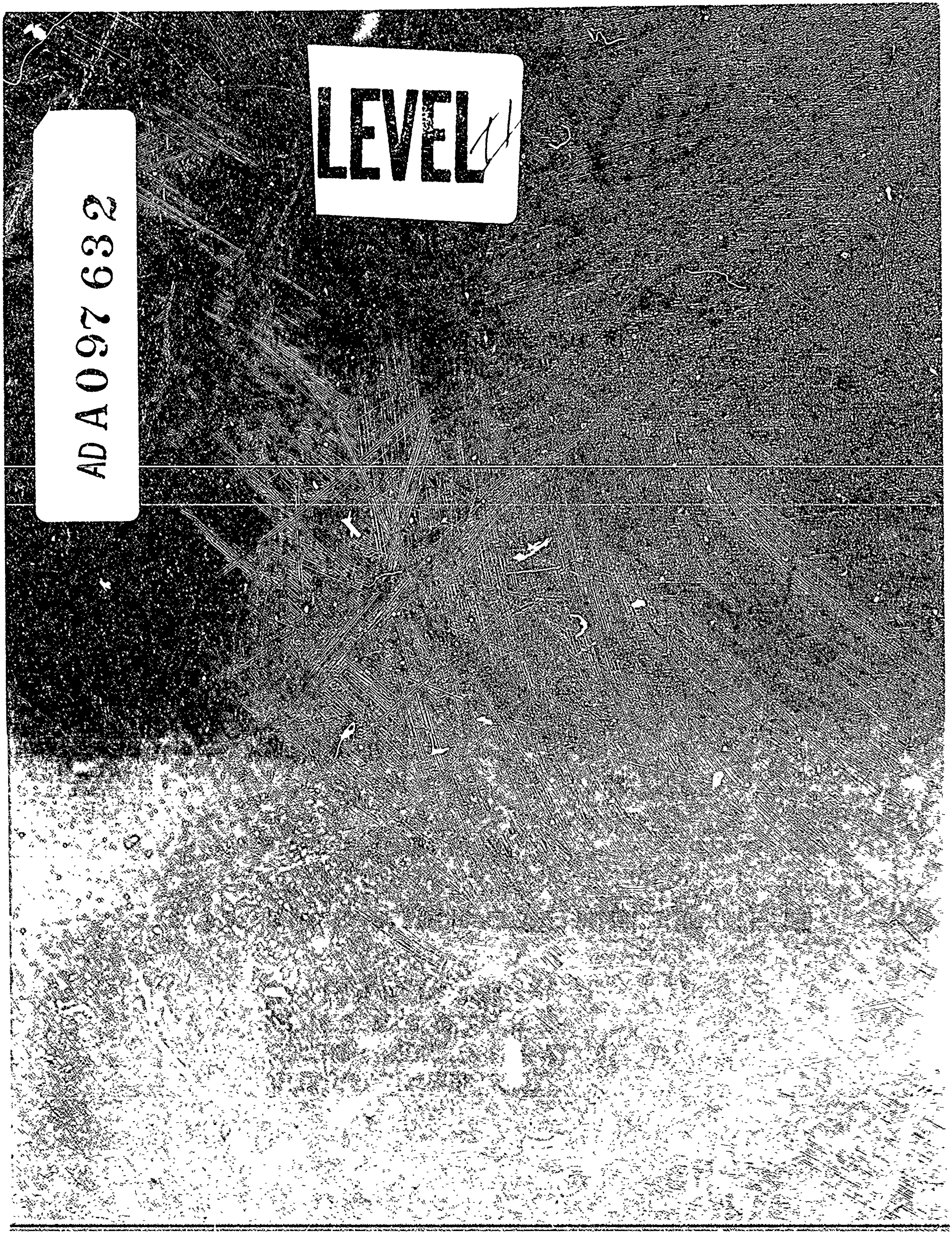

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The purpose of this investigation has been three fold: 1) to review the literature for experimental results which either contribute quantative tolerance data or data supporting mechanisms or criteria of injury; 2) develop new methods of investigating neck response to indirect loading; 3) further refine a mathematical neck model.

It has been found that retinal hemmorrhage or mild concussion were the threshold injuries produced in forward facing harnessed individuals subjected

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to 39-45 g sled acceleration impulses lasting on the order of 0.270 ms depending on head-neck orientation. On the other hand, field collision data indicates insignificant head-neck injuries of belted passengers from purely inertial loading of the head due to collisions at highway automotive speeds. However, in abrupt neck stretch experiments with cats it has been found that neck stretch and possible odontoid process - cord interaction are related to unconsciousness in this species. Tetanizing the cervical muscles reduced the incidence of "concussion" symptons produced in this animal. Collars on monkeys subjected to flexion producing occipital impacts, were reported to provide concussion protection.

Following work with a freshly dead, hemisectioned monkey head model tagged to measure shear strain, it has been postulated that highest shear strain in a pure rotational setup was found in the brainstem. This was caused by the brainstem pulling on the cervical cord restrained by dentate ligaments as the brain attempted to rotate inside the skull. Another group using anesthetized monkeys accelerated on a Hyge translational sled, stopped the body less abruptly than the head, producing a range of symptons in the monkey from short concussion to death. Pathological examinations showed that they produced many neck injuries and large amounts of brainstem damage. Recent high speed work with hemisectioned cadaver necks shows that abrupt arrest of the body at only 3.9 m/s (11 ft/sec) causes inertial head loading to flex and stretch the cervical spine up to 2.54 cm (1 in).

While no clear picture of tolerable levels or even criteria of injury can be pulled out of this array of evidence, it is clear that until the problem can be better defined, relative motion between head and neck and a position which will minimize stretch in the retinal attachments should be part of protective systems, where feasible, when abrupt $-G_x$ can be anticipated.

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TOLERANCE OF THE HEAD AND NECK TO $-G_x$ INERTIAL LOADING OF THE HEAD

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Summary

The purpose of this investigation has been three fold: 1) to review the literature for experimental results which either contribute quantative tolerance data or data supporting mechanisms or criteria of injury; 2) develop new methods of investigating neck response to indirect loading; 3) further refine a mathematical neck model.

It has been found that retinal hemmorrhage or mild concussion were the threshold injuries produced in forward facing harnessed individuals subjected to 39-45 g sled acceleration impulses lasting on the order of 0.270 ms depending on head-neck orientation. On the other hand, field collision data indicates insignificant head-neck injuries of belted passengers from purely inertial loading of the head due to collisions at highway automotive speeds. However, in abrupt neck stretch experiments with cats it has been found that neck stretch and possible odontoid process - cord interaction are related to unconsciousness in this species. Tetanizing the cervical muscles reduced the incidence of "concussion" symptoms produced in this animal. Collars on monkeys subjected to flexion producing occipital impacts, were reported to provide concussion protection.

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A. INTRODUCTION

1. Human Volunteer Exposure

Col. John P. Stapp was one of the pioneers of voluntary submission to forward facing linear deceleration (eyeballs out) head loading. In his studies, twelve healthy male subjects were exposed to acceleration at right angles to the long axis of the body during high speed braking of a rocket sled on which they were riding. Using an inverted V leg strap added to the shoulder straps and lap belt assembly, they sustained exposure to 45.5 g at 493 g/sec rate of onset of deceleration, and up to 38.6 g at 1370 g/sec. Stapp suffered mild retinal hemorrhage on a run in which the peak mouth accelerometer registered about 42 g, total duration around 270 ms.[1] He noted that much higher levels can be survived, although reversible injurious effects may intervene (1). Stapp noted that in one test (Run 133) the "Subject failed to follow instructions to keep his head down," (head and neck flexed forward as nearly horizontal as possible to minimize neck injury and chest impact) his helmet flew off during deceleration and he lapsed into brief unconsciousness on the sled. He revived and relapsed into unconsciousness lasting about half a minute, responding to being slapped on the back of the neck with head held down to knee level.

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[1] Verbal communication with the New York State Boxing Commission Chairman indicated that retinal detachments are a growing concern in that sport. Although gloves have been redesigned in recent years to prevent thumbs from being used to gouge the eye of an opponent, it is conjectured by the author that these injuries are due to fromtal blows causing relatively high $-G_x$ impulses. Preliminary work on dummies has indicated that blows of 40 g, 8-10 ms duration are easily produced by an amateur wearing regulation 8 oz gloves.

In a repeat run to determine what caused the loss of unconsciousness in Run 133, Stapp, with head held down to aviod amplification of head loading, did not suffer unconsciousness but did sustain comminuted fractures or radius and ulna of the right arm. Gadd (2) has done an analysis of some of the more severe runs by the Stapp group and estimated from the unixial head acceleration oscillographs that considerably higher biaxial accelerations were experienced with Severity Indices to 1500.

The impact enviornment of Stapp and his co-workers was evidently in excess of what is generally experienced in motor vehicles. With regard to the applicability of head injury (concussion) criteria (HIC) to seat belt system compliance with U.S. Government motor vehicle safety standard tests, auto manufacturers petitioned successfully for removal of the criteria partly on grounds that field collision data does not indicate that head movement (without striking an object) by shoulder-belted vehicle occupants is a serious injury producing factor (3). Part of the reason for rescinding the HIC was also artifactual head waving response by existing dummies.

2. Anesthetized Animal Exposure

Hollister, et al (4) clamped the heads of anesthetized cats in a stock with the body unsupported below and allowed them to drop in guided free-fall. The stock was arrested abruptly, causing the neck to be stretched by the inertial loading of the body producing symptoms of experimental con-concussion interpreted by loss of corneal reflex. They also performed the experiment with the body supported, and required higher energy to produce "concussion." The symptoms were also produced by a blow and by static neck stretch. They found that the location and amount of histological damage were not discernible between cats which were dropped and those which received a blow. Brain neuronal damage was found similar to those reported previously in experimental animal head impact tests. However the neck stretch experiments produced more pronounced damage around C1-C2 on the medio-ventral surface of the cervical spinal cord. They attributed the mechanism to a sharp flexion of the cord around the odontoid process. It was conjectured that a subluxation of the odontoid process during a forced position change might contribute to aggravate the effect. Tentanizing the cervical muscle reduced the incidence of "concussion."

These researchers confronted the same problem others have experienced in head injury work, that of separating the effects of variables. In addition to neck stretch, when the stock is arrested, a blow is delivered to the bottom of the skull due to the inertia of the head. Modification of the apparatus failed to produce reproduceable, reliable test results.

Ommaya and Rockoff (5) have produced concussion in experimental monkeys with and without a cervical collar, the latter associated with the most severe concussive effect and brain damage. It is not certain whether the increased effect was caused by more neck stretch without the collar or because of higher head acceleration without the mass of the collar.

Interesting results were obtained by two Japanese teams using a Hyge^{R} translational sled in anesthetized monkey experiments (6, 7). They accelerated the whole body of the primates and stopped the head first, followed by a more gradual deceleration of the body, producing a range of neural response from short duration concussion to death. No relation was found between brain injury and intracranial pressure but many cervical cord and brainstem injuries were produced.

3. Fresh Tissue Animal Brain Model

Hodgson and Thomas (8) devised a model in which shear strain could be measured using a freshly dead monkey brain - cervical cord hemisection. It was subjected to pure translation, pure rotation and a mixed motion mode. Rotation produced the highest shear strains, which were 3-4 times higher than had been predicted by mathematical models, and were measured in the brainstem rather than as predicted in the peripheral cortex. It was postulated that rotational motion permits the brain to rotate within the cranial cavity to the degree to which the tethering action of vessels and spinal cord will allow. This action pulls on the cord through the brainstem, stretching both, due to the reaction of the dentate ligaments connected on either side of the cervical cord pia mater to dura. Kahn (9) and later Schneider (10) discussed the possible role of strong dentate ligaments on the exertion of stress on the cord during accidents.

4. Observation of Cervical Spine Motion

4.1 Human Cadaver Neck Models

Recent work with hemisectioned cadaver necks by Wayne State University researchers has helped to visualize the motions of the cervical spine when subjected to experimental $-G_x$ impact. In this configuration the neck stretches due to inertial loading of the head as it attempts to continue moving forward when the body stops. Excerpts taken from film exposed at 500 fps following arrest of the body at only 3.9 m/s (11 ft/sec) are shown in Figure 1. The cervical spine is seen on film to begin in the normal convex forward (lordotic) curvature; straighten as the head moves linearly and with approximately 13 mm (0.5 in) elevation during the first 30 ms, and, gradually curve into flexion. The spine, which began at 114 mm (4.5 in) length, stretches to a maximum of approximately 140 mm (5.5 in) when the chin contacts the chest at 90 ms, after a 60 degree rotation of the head. Figure 2 is a blow-up of the cervical spine near maximum flexion. It is not known how much the cord stretches during this maneuver.

4.2 Spine Displacement Transducers

Another approach to the measurement of cervical spine motion during impact to the almost intact cadaver or anesthetized animal spine, is by means of a vertebral displacement transducer. It utilizes a Hall effect cell which can measure magnetic field strength. The sensor provides a linear single-ended output which is a function of magnetic field intensity. In this application it is desirable to vary the strength of a magnetic field around the Hall sensor in a manner that is proportional to the relative vertebral deflection so that the output of the Hall effect sensor is proportional to relative deflection.

The Hall effect sensor has the advantages of small size, simple circuitry and being relatively impervious to fluids. The difficulty is in obtaining enough linear output for a limited range of displacement. It is necessary therefore to condition the output with a logarithmic amplifier to get a linear output. This arrangement has been tried and appears to be linear within 4% over a limited range of 3.0 mm (0.12 in). It is now being set up on a simulated cervical spine and tested for cross-talk, as shown in Figure 3.

4.3 Cineradiography

A cineradiographic technique is also being examined for the visualization of neck motion during impact. The x-ray image is projected onto a television screen which records the resultant motion of the cervical vertebrae due to a quasi-static load. This method has the advantage of observing spine movements in the intact neck to witness such things as process fracture due to bone interference or ligament tension under extreme motion. It has the current disadvantages of: relatively small field (just encompasses the cervical spine); shoulder superimposition in the cadaver is difficult to overcome; and slow rate of phosphor decay in the image intensifier limits the upper framing rate to about 200 fps. Information on neck stretch and motion of the dens from any or all of the above techniques is for refinement of a mathematical spinal model under development in this study.

5. Tolerance Criteria and the Effect of Head Protection on the Neck

Patrick and Mertz (11) have investigated the effects of the added mass of helmets on neck reactions of volunteers and cadavers subjected to an acceleration environment producing hyperflexion of the head and neck. They found that both magnitude and the location of the mass on the head contribute to an increase in the neck reaction. The effective moment at the occipital condyles was determined to be the critical injury criterion. Maximum voluntary static moment at the occipital condyles was 35 N.m (25.9 ft-lb), while under dynamic conditions the same volunteer reached 88 N.m (65 ft-lb). In general, it was found that the equivalent moment at the occipital condyles was higher for the cadavers than for the human volunteer under the same conditions. The restraint of the neck musculature of the volunteer reduced the peak reaction at the occipital condyles.

Ewing, et al, have done extensive work in the area of head-neck hyperflexion movements from $-G_x$ accelerations

(12, 13). He estimates that Stapp's $-G_x$ sled acceleration run (1) may have caused acceleration measured at his mouth of 200 g. Ewing also has reported a complete disarticulation of the atlanto-occipital junction on an 89 N (20 lb) rhesus monkey subjected to a 160 $-G_x$ sled acceleration.

6. SUMMARY

The work of many researchers with anesthetized animals, brain models, human cadavers and volunteers indicates that:

1. The amount of relative movements at the cranio-spinal junction may be vital to whether or not consciousness is lost in high acceleration environments which produce hyperflexion of the head and neck. Such motion should be minimized.
2. The odontoid process (dens) may be intimately involved in the injury process to the cord as it bends over the dens in this maneuver. Subluxation of the dens may aggravate the injury to the cord.
3. Wearing a helmet will aggravate the problem by virtue of added bending and axial and shear loads at the atlanto-occipital junction due to higher mass and CG of the head. A helmet presents an advantage, however, in providing an attachment point on the head with which to fasten a belt strap[1] inertia cable or collar limiting head-neck motion to impact.

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[1] Such as used by U.S Navy football players to prevent excessive bending of the neck.

4. A flexed head and neck with chin on sternum has been found helpful to avoid losing consciousness and possible retinal damage from $-G_x$ impact but should be considered with respect to possible increased hazard from $-G_z$.

REFERENCES

1. Stapp, J. P.: "Human Exposures to Linear Deceleration, Part 2. The Forward-Facing Position and the Development of a Crash Harness, AF Technical Report No. 5915, February 1952.

2. Gadd, C.W.: "Tolerance Severity Index in Whole-Head Non-mechanical Impact." Proceedings of the Fifteenth Stapp Car Crash Conference, Coronado, California, November 1971, p. 809-816.

3. Department of Transportation National Highway Traffic Safety Administration (49 CFR Part 571), Docket No. 67-7, "Occupant Crash Protection Head Injury Criterion."

4. Hollister, N.R., Holley, W.R., Horne, R.G. and Friede, R.: "Biophysics and Concussion." WADC Technical Report 58-193 and ASTIA Document No. AD 2033885, September 1958.

5. Ommaya, A.K., Rockoff, S.D. and Baldwin, M.: "Experimental Concussion - A First Report." Journal of Neurosurgery, 21:249-265, 1964.

6. Tsubokaga, T., Nakamura, S., Hayashi, N., Miyagami, M., Taguma, N., Yamada, J., Kurisaka, M., Sugawara, T., Shinozaki, H., Goto, T., Takeuchi, T., and Moriyasu, T.: "Experimental Primary Fatal Head Injury Causes by Linear Acceleration-Biomechanics and Pathogenesis." Tokyo, Japan.

7. Komaki, U., Kikuchi, A., Horii, M., Ono, K., Kitagawa, N., and Matsuno, M.: "The Research on the Fatal Level of the Primates Head Impact Tolerance." The Japan Automotive Research Institue, Inc., (JARI) October 11, 1978.

8. Hodgson, V.R. and Thomas, L.M.: "Acceleration Induced Shear Strain in a Monkey Brain Hemisection" (719023) Twenty-Third Stapp Car Crash Conference, San Diego, California, p. 589-611, October 1979.

9. Schneider, R.C.: "A Syndrome in Acute Cervical Spine Injuries for Which Early Operation is Indicated." Journal of Neurosurgery, 8:360-367, 1951.

10. Mertz H.J., and Patrick, L.M.: "The Effect of Added Weight on the Dynamics of the Human Head," U.S. Army Natick Laboratories, Report on Contract No. DDAG-17-67-C-0202, Natick, Mass., 1971.

References (Continued)

11. Ewing, C.L.: "Injury Criteria and Human Tolerance for the Neck." Aircraft Crashworthiness, University Press of Virginia, p. 141-151, 1975.

12. Ewing, C.L., Thomas, D.J., Beller, G.W.J., Patrick, L.M., and Gillis, D.B., "Dynamic Responses of the Head and Neck of the Living Human to $-G_x$ Impact Acceleration, "Proceedings of the Twelfth Stapp Car Crash Conference, Society of Automotive Engineers, p. 424-439, New York, 1968.

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